

CREATING VALUE

through innovation and technology

Long-distance tie-backs

Transforming the economics of field development

Developing cost-efficient pipeline materials

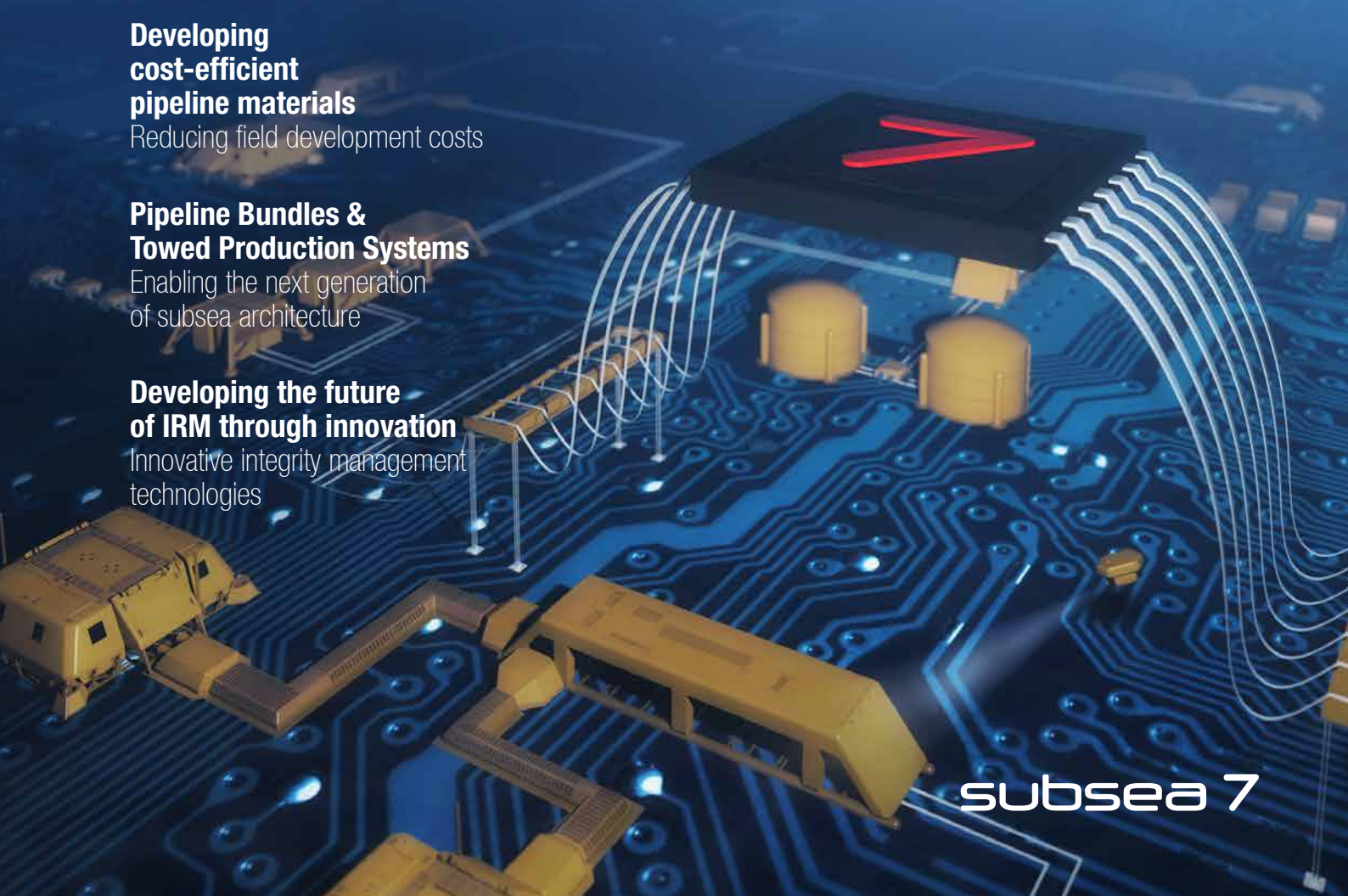
Reducing field development costs

Pipeline Bundles & Towed Production Systems

Enabling the next generation of subsea architecture

Developing the future of IRM through innovation

Innovative integrity management technologies



Welcome to deep7 2017

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Delivering on technology

By **Thomas Sunde** | Vice President Technology

Through Company-wide engagement and strategic road-mapping, we have successfully implemented a new, more client-responsive technology development process which is already paying dividends: we are delivering technological innovations and solutions to the market that create real value.

This is the third issue of deep 7 that I have introduced, and, when I look back at the previous two, it confirms how far Subsea 7's technology development programme has now come. This is where we aimed to be when we started the process of re-appraising the changing market and business drivers back in 2014. We had, and continue to have, open engagement with clients and partners to identify high-impact industry challenges, especially for current and near-future developments. From these many consultations, we developed a clear view of the steps we needed to take to enable our clients to achieve their goals.

We have now taken many of these steps, and in the following pages you will read examples of how we are consistently delivering value in many different areas of subsea technology, including:

- greatly extending the scope of long-distance tie-backs
- reducing the material and installation costs of pipelines
- developing affordable internal flowline corrosion protection
- designing cost-effective solutions to unlock unviable HP/HT reserves
- improving the efficiency of integrity management.

Working with the University of Cambridge's Institute for Manufacturing (IfM) and other established partners, we have implemented a highly responsive innovation and technology management strategy which enables us to continue delivering real change and value to clients in high-impact areas.

The process has equipped us with powerful, research-based management tools to ensure that we focus our investment and resources on developing key technological products and solutions. Following this clearly defined innovation pathway has led us to commit to collaboration and acquisition to develop the capabilities that we need.

Through the strengthening of our technology portfolio and field concept design capabilities, we are now in a position to assist our Clients in implementing game changing solutions, unlocking cost savings and efficiency gains that only a few years ago would have been impossible. To identify prime adoption opportunities for the new technologies, we work closely with our Field Development Group on establishing early engagement with clients. We are getting results from our established technology partnerships. The Field Development Group draws on the capability of our alliance, KG7, with KBR and Granherne, to combine independent design perspectives with advanced technological know-how.

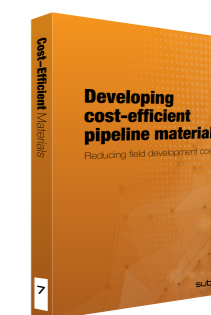
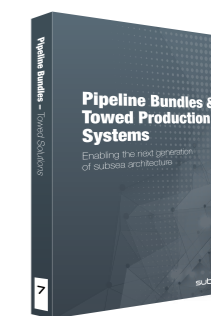
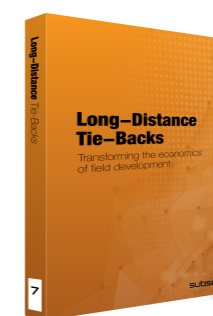
The Subsea Integration Alliance with OneSubsea combines the market-leading subsea production systems and Subsea Processing systems with our own SURF systems, engineering and construction expertise and Life of Field (LOF) services, delivering effective alternative solutions to such challenges as very long tie-back distances.

Responding to the industry's focus on developing affordable internal flowline corrosion protection, we acquired polymer lining technology specialist Swagelining Ltd last year. In addition, we work in close collaboration and partnerships with a number of leading suppliers in our industry to develop and deliver new cost effective materials to the market.

We are now delivering on a wide range of technologies, but in this issue of deep 7, we have highlighted four particularly significant areas of development. Long-distance tie-backs are a cost-efficient alternative to FPSO or platform-based facilities. Operators are looking for high-performance flowline heating systems to enable even longer tie-back distances to be achieved. To achieve this, we have developed a unique range of heating technologies, including an effective alternative Cold Flow Technology (CFT) approach (Page 12).

These technologies, either individually or in smart combination with subsea processing, deliver significant benefits to clients. We are enabling more cost-effective field developments; we allow existing host facilities to be revitalised; and we are opening up new, game-changing operational concepts. The material and installation costs of pipelines can represent a significant part of the subsea infrastructure costs, so we are currently qualifying high-strength linepipe for applications in HP/HT and deepwater application environments (Page 6).

Our Global Pipeline Welding Development Centre has an outstanding track record of collaborating with leading pipeline manufacturers to extend the applications of lighter, stronger and more cost-efficient materials. Through its work, we are



Subsea 7 is developing a wide range of technologies. In this issue of deep 7 we are highlighting four particularly significant areas of development.

delivering significant cost savings in many challenging subsea applications through the introduction of new pipeline materials.

We have an even longer history – extending back almost 40 years – in the design and onshore prefabrication of our unique Pipeline Bundles (Page 16).

These self-contained subsea systems transform the commercial viability of marginal HP/HT accumulations in particular, and also open up new business models offering cost reductions of up to 20% over conventional pipelay methods.

Over 80 Bundles have been installed to date by Subsea 7 in UK, Norwegian, Dutch and Australian waters, and we plan to expand this unique technology on a global basis. Another key area of strategic technological innovation has been in Inspection, Repair and Maintenance (IRM) activities (Page 22). i-Tech Services is drawing on cutting-edge data management and geographical information systems to radically increase maintenance efficiency and introduce higher-quality decision making for all Life of Field activities. Developing new technologies

is a very demanding activity for any company or organisation, requiring focus, discipline, open-mindedness and creativity.

However, as the examples in these pages confirm, the successful delivery of a new technology is one of the most rewarding experiences in industry. We look forward to many more, equally satisfying steps on this long-term journey to which we have committed. •



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We continue to have open engagement with clients and partners to identify high-impact industry challenges, especially for current and near-future developments.

SUSTAINING INNOVATION

By **John Saiz** | Principal Industrial Fellow
Institute for Manufacturing (IfM) Education and Consultancy Services

Subsea 7's future is underpinned by a highly client-responsive technology management strategy that is helping it to become the world's most innovation-focused seabed-to-surface engineering company.

Formerly Chief Technology Officer at NASA's Johnson Space Center, John Saiz and the team from the Institute for Manufacturing (IfM) at the University of Cambridge have been working with Subsea 7 since 2015 to sustainably grow and diversify its technology and product development activities. The team has used some of the latest research-based innovation and technology management tools to enhance the process for bringing to market new products and solutions in response to identified client needs.



John Saiz.

The technology development team at Subsea 7 consistently produces exceptionally innovative ideas and concepts and recognised that their innovation pathway could be improved by engaging with clients and other partners in the early stages of field developments. These engagements clarified what strategic areas of technology are of greatest importance to the company and helped to define what technological resources and capabilities are needed.

Quality function deployment techniques were used to transform client needs into value streams and opportunity feasibility assessments to develop a balanced portfolio for the future. In addition, strategic open innovation was initiated to enable the company to diversify its innovation process across organisational boundaries.

Subsea 7 is already experiencing positive results from this strategy with its successful expansion into offshore renewable energy.



Value mapping delivers tangible benefits to Subsea 7's clients by maximising value in a number of sensitive areas

The process identified a number of high-impact areas on which to focus. One is to introduce a value perspective and sustainability thinking (i.e. value mapping) to support Subsea 7's clients in maximising investment returns and value.

Subsea 7 is building on its innovation management capabilities to promote an

environment of creativity and inventive thinking. This will continuously improve its organisational culture in collaboration with each of its clients and alliance partners to create an organisation that is greater than the sum of its parts.

This collaborative environment is creating industry-leading, cross-company innovation, combining the talents from multiple partners.

The three fundamental themes for success in this model – robust commercial arrangements, unhindered collaboration between partners and effective operational implementation – are firmly established and now reinforce Subsea 7's ability to successfully deliver needs-driven new technologies to its clients. ●



Bundle System design management workshop.



DEVELOPING COST-EFFICIENT PIPELINE MATERIALS

By **Richard Jones** | Strategic Technology Development Manager

Historically, traditional seamless quenched and tempered Grade X65 or X60 linepipe has provided the optimum balance of strength, toughness, weldability and sour service corrosion performance required for typical risers and flowlines installed offshore.

Deeper water production, cost efficiency, higher pressure and temperature wells and more aggressive service environments are testing the limits of conventional pipeline material solutions.

The increasing need for improved performance is driving the selection of higher specification pipeline materials, invariably resulting in increased fabrication and installation costs which can critically impact the economic feasibility of field development.

A key driver in Subsea 7's strategic technology development programmes is the need for more cost-efficient pipeline material solutions and associated fabrication technologies for the CAPEX constrained oil price environment.

High-strength steels

Pipeline installation in deeper waters with higher operating pressures can benefit from the use of higher-strength steels exceeding X65. Decreased pipe wall thickness, derived through higher strength steel, can contribute to lower material procurement and fabrication costs. The reduced pipeline weight decreases the installation top-tension requirement and therefore extends the capacity of existing Reel-Lay vessels to even greater water depths.

Pipeline weight reduction also creates opportunities for increased flexibility in riser design options to further optimise cost efficiencies. For example, a Steel Lazy-Wave Riser (SLWR) design in X65 could be replaced with a more lightweight Steel Catenary Riser (SCR) design in X80. Alternatively, buoyancy module requirements for an SLWR could be reduced by the use of high-strength steels.

Subsea 7 has recently performed qualification programmes for X80 pipe in collaboration with steel tubular

manufacturer Vallourec for Reel-Lay installation, using welding solutions that meet the strength and toughness requirements of DNV-OS-F101.

This development has demonstrated that X80 pipe can be fabricated using welding and inspection technologies similar to those deployed for X65 pipe but with the benefit of a reduced wall thickness.

Fatigue testing of reeled full-scale test samples has exceeded API X' design requirements and therefore meets typical Gulf of Mexico riser design requirements.

Despite the slightly higher hardness levels which are inevitable with higher strength steels, sour service corrosion (SSC) testing has also demonstrated their capability to meet the needs of mildly sour environments. Subsea 7 can now offer pipeline material and fabrication solutions to support the design of offshore risers and flowlines in X80 pipe.

Our next focus will be on the use of even higher-strength steels, exceeding X80, which offer the prospect of further reductions in pipeline wall thickness and weight. These materials bring new challenges, not the least of which is their less favourable weldability. In such cases, alternative solid-phase welding processes may offer an advantage over conventional welding solutions.

High-Frequency Welded Pipe (HFW)

HFW pipe comprises longitudinally welded pipe manufactured from coiled strip and cut into individual pipe lengths. The use of HFW pipe can offer a number of advantages over other pipe types including improved surface condition and superior dimensional tolerances.

However the major driver for the use of HFW pipe is the reduced cost. Due to the efficient forming method, the cost of HFW

pipe is typically 40% less than seamless pipe and 20% less than Submerged Arc Welding pipe. An analysis of the historic potential cost savings over the past 20 years indicates that up to 53% of pipelines installed by Subsea 7 could have been manufactured as HFW pipe, resulting in a cost saving of \$260m.

We anticipate a growing number of successful applications of HFW pipe, including water injection lines with polymer lining where the improved dimensional tolerances are an added benefit. HFW pipe of this type has been installed by both Reel-Lay and as Bundle fabrications, and HFW pipe has also been utilised as outer pipe for Pipe-in-Pipe systems and as sleeve pipe for Pipeline Bundles.

HFW pipe has some limitations, in particular the restricted pipe size range and low temperature toughness. Subsea 7 continues to work with pipe suppliers to address these manufacturing limitations and also to extend the range of qualified applications, including for sour service.

Corrosion-Resistant Alloy (CRA)

The use of CRA mechanically lined pipe provides a highly cost-efficient alternative to the use of metallurgically clad pipe for many applications requiring improved corrosion performance.

Working closely with manufacturer Butting, Subsea 7 has pioneered the Reel-Lay installation of mechanically lined BuBi® pipe. Internal hydrostatic pressurisation of the pipeline during reeling and unreeling is used to completely eliminate the risk of liner wrinkling. The use of BuBi® pipe is now well established for production flowlines installed by Reel-Lay and for Bundle fabrication.

BuBi® pipe has also been deployed for SCR applications where fatigue loading is not critical. However, recent qualification

programmes have demonstrated a capacity to meet more critical fatigue service requirements avoiding the need to use metallurgically clad pipe for such applications.

BuBi® lined pipe can be extended to high-strength steel substrate pipe which is not normally possible with metallurgically clad pipe. Butting has demonstrated a capability to manufacture CRA-lined X80 pipe using similar equipment to that used for lined pipe in X65 material, making it possible to provide high-strength steel pipe with improved corrosion performance.

Girth welding development by Subsea 7 required a novel approach utilising internal welding of the CRA material followed by external welding using C-Mn weld metal.

This welding approach ensured that the weld metal strength overmatch required for Reel-Lay could be achieved, which would otherwise be difficult to accomplish with a conventional dissimilar weld metal joint. The suitability of X80 BuBi® has been demonstrated by full-scale reeling simulation.

Butting is presently engaged in developing manufacturing technology to eliminate the need for internal pressurisation of BuBi® pipe for reeling.

This is accomplished through the use of an adhesive layer between the substrate pipe and the liner which results in an enhanced grip condition that can be maintained during reeling to prevent liner wrinkling. Subsea 7 will work closely with Butting over the coming months to qualify this new Mechanically Lined Pipe product for Reel-Lay applications.

Polymer-lined pipe

The use of polymer-lined pipe, inserted by the Swagelining process, is well established for the fabrication of corrosion resistant

water injection lines. Until now, it has been necessary to use a proprietary CRA end connector, WeldLink®, to terminate the internal liner for such applications as tie-in connections.

Procurement and qualification requirements for WeldLink® connectors are cost-intensive. Swagelining has recently developed and qualified a matching polymer connector, LinerBridge®, to replace the need for a CRA connector.

With LinerBridge®, the polymer liner welds are accomplished using an electrofusion process adapted from proven technology from the gas utilities industry, and the external carbon steel welds are made conventionally without risk of damaging the underlying liner material.

The qualification programme has included both simulated reeling and hydrostatic testing.

The availability of the LinerBridge® connector now makes the use of polymer-lined pipe for larger-diameter water injection lines installed by S-Lay and for dynamic steel catenary risers an attractive economic alternative to clad pipe.

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The next boundary to be extended for polymer linings is their use for hydrocarbon service.

The main technical challenge to be addressed will be to mitigate and manage the risk of gas permeation through the polymer lining, which would expose the steel substrate to a corrosive environment.

Composite materials

When faced with the need to adapt to harsher conditions, the oil and gas industry typically leans towards scaling-up established technologies rather than opening up to new materials and tools.

This approach has major limitations where components become too heavy, too expensive and too complex to manufacture or install, which can especially be the case when considering High Pressure/High Temperature (HP/HT), deep and ultra-deepwater developments.

While constantly extending our current capabilities, Subsea 7 also continuously evaluates alternative materials and methods for development. We have successfully replaced steel with composites in many subsea structures such as protection covers or plates.

Although driven by technical requirements, these alternative products are also commercially attractive, which is the ultimate goal for our clients.

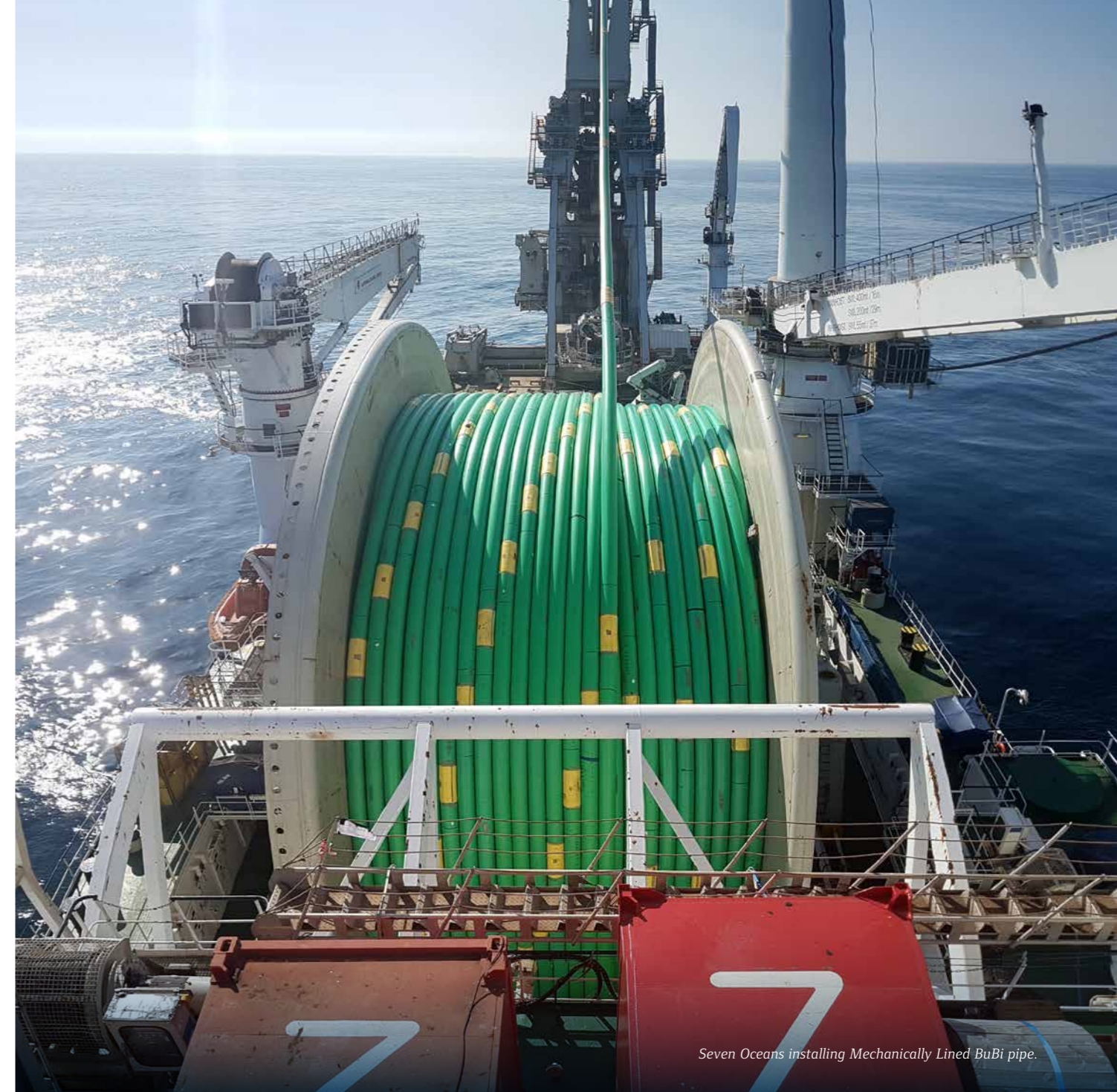
We are also evaluating alternative pipeline materials such as thermoplastic composite pipes (TCP), assessing both their technical and commercial capabilities.

Pipeline in TCP materials provide a fully bonded structure with a smooth bore giving superior corrosion resistance, flow assurance and thermal performance capabilities to comparable steel pipeline. In addition, the combination of low weight and high strength of TCP pipeline material makes it an attractive enabling solution for deepwater SURF architecture.

Challenges still remain to be met in practical pipeline fabrication and installation before some of these technical advantages can be realised cost-effectively.

Subsea 7 continues to extend the boundaries of innovative pipeline material development to reduce the costs of pipeline fabrication.

This enables our clients to benefit from new technologies that can transform the economics of field development. •



Seven Oceans installing Mechanically Lined BuBi pipe.



Richard Jones joined Subsea 7 in 2008 and manages our strategic technology programmes for materials, welding, NDT and FJC for pipeline fabrication. He previously spent 30 years with The Welding Institute in technology development and engineering consultancy for a range of industries. He has BSc and PhD qualifications in Metallurgy and Materials.

POLYMER CORROSION BARRIER

By **Allan Feeney** | Technical Development Manager, Swagelining Limited



Polymer liners are widely used to fabricate corrosion resistant subsea water injection pipelines due to their cost-effectiveness and reliability. Polymer lining specialists Swagelining Limited, a market leader in the industry with over 30 successful subsea projects, has demonstrated a product with a 50 year design life that offers typical cost reductions of around 35% over Corrosion-Resistant Alloy (CRA) mechanically lined pipe.

51% of all pipeline failures are a result of internal corrosion, with 7 years the typical life expectancy of an unlined water injection pipeline, according to a JIP completed by North Sea operators. In addition to Swagelining's 50-year product life span, clients can also benefit from its qualities of reduced weight, improved flow assurance, lower inspection requirements, reduced requirement for corrosion inhibition and improved oil recovery due to ensured cleanliness of the injection fluid.

For applications where an all-polymer corrosion barrier is preferred, Swagelining, which was acquired by Subsea 7 in 2016, has developed a new proprietary polymer connector technology, LinerBridge®.

LinerBridge® extends the capability of Swagelining technology by offering a fully-weldable all-polymer corrosion

barrier which reduces the costs and risks associated with corrosion-resistant pipelines by eliminating the need for CRA welding.

Its major advantage is that it makes polymer-lined pipeline technology less complex and ultimately easier to use. LinerBridge® uses robust and proven electrofusion welding technology adapted from the onshore utilities' gas industry to provide a continuous polymer corrosion barrier from pipeline end to end. The carbon steel pipeline can then be safely welded over the top of the polymer connector.

For subsea installation, the connector can be deployed in all pipelay installation methods including Reel-Lay, S-Lay, J-Lay and towed Bundles. The connector is fully qualified following successful final reeling trials on a water injection pipeline for the Wintershall Maria development.

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Developing affordable internal flowline corrosion protection has significant game-changing potential

Another area of focus for the company is the development of polymer lining solutions for hydrocarbon transporting pipeline applications. Swagelining is currently working with The Welding Institute (TWI) and Saudi Aramco on a Joint Industry Project to assess the corrosion barrier performance of a range of polymer materials and new technologies which may prove suitable for these challenging applications.

For a polymer liner solution to provide a robust corrosion barrier in a hydrocarbon application, it must be able to manage the potential for accumulation of high annular gas pressures and volumes due to the gas diffusion through semi-permeable liner materials.

By developing an effective solution to this issue, Subsea 7 and Swagelining aim to offer polymer-lined pipe as a cost-effective, resistant and reliable alternative to clad and CRA pipe for hydrocarbon transporting pipelines. •

THE SWAGELINING PROCESS

The process relies upon the elastic nature of the polymer material and residual strain to provide a tight-fitting pipeline liner solution. Utilising our bespoke liner design software, a polymer liner pipe of greater outside diameter than that of the inside diameter of the carbon steel host pipe is pulled in tension through a reducing die.

While under tension, and at a reduced diameter, the polymer liner pipe is pulled through the length of carbon steel host pipe. Typically this can be up to 1.5km in a single operation. Once in position, the tension is released and the polymer liner pipe is allowed to revert, creating an effective corrosion barrier as the liner endeavours to expand back towards its original size.



Allan Feeney is responsible for technology development at Subsea 7's recently acquired polymer lining specialist, Swagelining Limited. He has over 20 years' engineering experience with particular focus in product design and processing with polymers, and led the development of Swagelining's innovative LinerBridge® connector. Allan has a Master's Degree in Manufacture and Design for Polymer Products from the London Metropolitan University.

LONG-DISTANCE TIE-BACKS

TRANSFORMING THE ECONOMICS OF FIELD DEVELOPMENT

By **Olivier Lodeho** | Strategic Technology Programme Manager for Flowline Systems
& **Sigbjørn Daasvatn** | Strategic Technology Programme Manager for Subsea Processing

An increasing number of offshore oil and gas developments can be made viable through eliminating the need to add expensive topside facilities.

In a low-cost oil and gas environment, one option for operating companies is to utilise effective subsea field development solutions that eliminate the need for traditional platforms or vessels with topside processing facilities.

This applies to geographically remote areas and small-pool developments of maturing brownfield areas. In such scenarios, lower development costs can be most effectively achieved through long-distance tie backs.

The economics of longer tie-backs are governed by a number of factors, including:

- The distance from existing installations
- The fluid temperature and pressure
- The water depth
- The recoverable volumes, reservoir size and fluid properties
- The potentially lower recovery rates compared with platform wells

The goal

We aim to achieve a situation where operators can tie-back remote fields to existing subsea facilities over longer distances than is currently possible.

To do this, we are currently identifying design drivers to define the optimal distances for passive insulated, actively heated and cold flow transport pipelines for thermal management and their smart combination with subsea boosting.



This technology is transforming the economics of field development in areas lacking existing infrastructure

In particular, by conditioning oil-dominated well-streams in cold flow systems (image above), remote fields can be connected to central host facilities using uninsulated small-diameter transport pipelines over very long distances.

This technology enables the prospect of total subsea production facilities with no requirement for manned platforms,

transforming the economics of field development.

Subsea 7 has an alliance with OneSubsea, a market-leading provider of Subsea Production Systems (SPS). Operating jointly as the Subsea Integration Alliance, this enables us to deliver effective combinations of SURF and SPS expertise.

The challenges of long-distance tie-backs

Especially in oil-dominated tie-backs, greater transport distances increase the technical and economic challenges of managing temperature and pressure. Subsea 7 has developed a number of technologies to enable long-distance tie-backs.

The thermal and hydraulic challenges are considerable. The carried fluid is a multi-phase mix of oil, gas, water and other chemicals which are likely to have a detrimental interaction over long distances. It is difficult to conserve the heat of production fluids over long distances and the fluid temperature is gradually

approaching ambient sea-water temperature.

Without active heating or conditioning of the fluid, this temperature reduction may lead to wax deposits on the pipe wall and hydrate formations during operating or shutdown conditions.

In terms of the thermal challenge, there are two alternative approaches for transporting hydrocarbons over long distances.

The traditional method is based on maintaining the temperature of the carried fluid by using passive materials such as wet coating, double-wall “Pipe-in-Pipe” (PIP) with an insulated dry annulus, or high-performance PIP using field-proven Izoflex™ insulation augmented by reduced internal pressure.

When the step-out distance increases, even high-performance passive insulation systems may no longer be capable of maintaining the required temperatures and need auxiliary heating to be applied through either electrical induction or hot water circulation systems.

Instead of maintaining the heat performance along the flowline, an alternative for very long tie-back distances is to cool down the fluid and thereby force wax deposition at the pipe wall in a controlled section of the flowline. Thereafter, wax is removed by a continuous local pigging operation inside the cooler. When temperature is reduced to ambient sea water temperature, and wax has been removed, no further wax deposition will occur and the fluid can be transported through simple uninsulated flow lines for export. A Wax Control Unit (WCU) based on our bundle and pipe-in-pipe technology is designed to perform this function.

This Cold Flow Technology (CFT) approach requires Subsea Processing (SSP) facilities near the field and is especially valuable for Arctic subsea developments.

Reservoirs may also have insufficient pressure to ensure production, in which case additional pumping becomes necessary. Through our Subsea Integration Alliance we have access to market-leading capabilities in boosting low-pressure of subsea production and processing systems.

Our alliance partner OneSubsea’s fully integrated processing, boosting and multiphase metering systems accelerate and enhance oil recovery, even in long-offset developments. Their multiphase pumps have achieved production rate increases of 30%–100%.

Current developments

Subsea 7 is developing technologies in all these areas to meet the challenges of long-distance tie-backs. Subsea 7 is the only subsea contractor with extensive experience in three different active heating technologies: Direct Electrical heating (DEH), hot water circulation within a PIP Bundle and Electrically Heat Traced Flowline (EHTF).

Active heating technologies are currently based on topsides power distribution, which by default limits the length of the flowline that can be heated. We are combining subsea electrical power distribution with our highly efficient EHTF technology to greatly extend the range of active heating technologies. Subsea 7’s EHTF technology is already

recognised as one of the most efficient active heating system in the current market thanks to its unique combination of vacuum in the PIP annulus and electrical wires. Through our technology development programme, we have acquired valuable expertise in managing cold spots at every location in a flowline along sizeable distances.

Applying thermal insulation or auxiliary heating to long-distance tie-back systems has mechanical design implications. We are currently examining the effect of uncertainties on such elements as in-place buckling behaviour, the spans of different modes of transportation, the effects of prolonged shutdown and the technical challenges of installation of long-distance tie-backs.

Subsea 7 is currently developing and qualifying the new WCU as part of a larger development programme supported by the Norwegian Research Council.

Extending the reach of EHTF

The Electrically Heat Traced Flowline, which has been developed by Subsea 7 in collaboration with manufacturer ITP Interpipe delivers the world’s leading flowline insulation performance.

EHTF is based on a thermally-enhanced Pipe-in-Pipe (PIP) design which requires lower power requirements than Direct Electrical Heating (DEH).

To maintain a constant fluid temperature at every location along a flowline requires a remediation of potential “cold spots”. Given the higher U-values of connections, structures or line-ends, when compared with the PIP flowline, this can result in overheating which compromises the power efficiency of the system.

With the advent of long-distance tie-backs, we have addressed the issue of cold-spot management through added insulation, local increases of heating power and the innovative re-design of key components, including the “Thermally Efficient Ring Arrangement” (TERA), which complies mechanically with reeling conditions while mitigating heat losses.

We have also extended the reach of EHTF tie-backs by developing efficient subsea electrical distribution systems, based on reliable, low-maintenance components, which supply the EHTF heating elements at regular locations along a flowline.

This system greatly extends the length of heated flowlines and offers increased operational flexibility and reliability, while also allowing power outputs to be adapted to changing heating requirements via simple switching controls.

Another effective technology for enabling long-distance tie-backs is Direct Electrical Heating (DEH), which is based on piggy-backing a heated electrical power umbilical onto a wet-coated insulated pipeline. We have a strong track record in this technology, including the world's first implementation of reeled CRA-lined carbon steel pipe with DEH active heating on Wintershall's Maria development in the Norwegian Sea.

We also installed the deepest DEH system implemented to date, for Chevron's Lianzi Project at a length of 43 km and water depth of 1070 m.

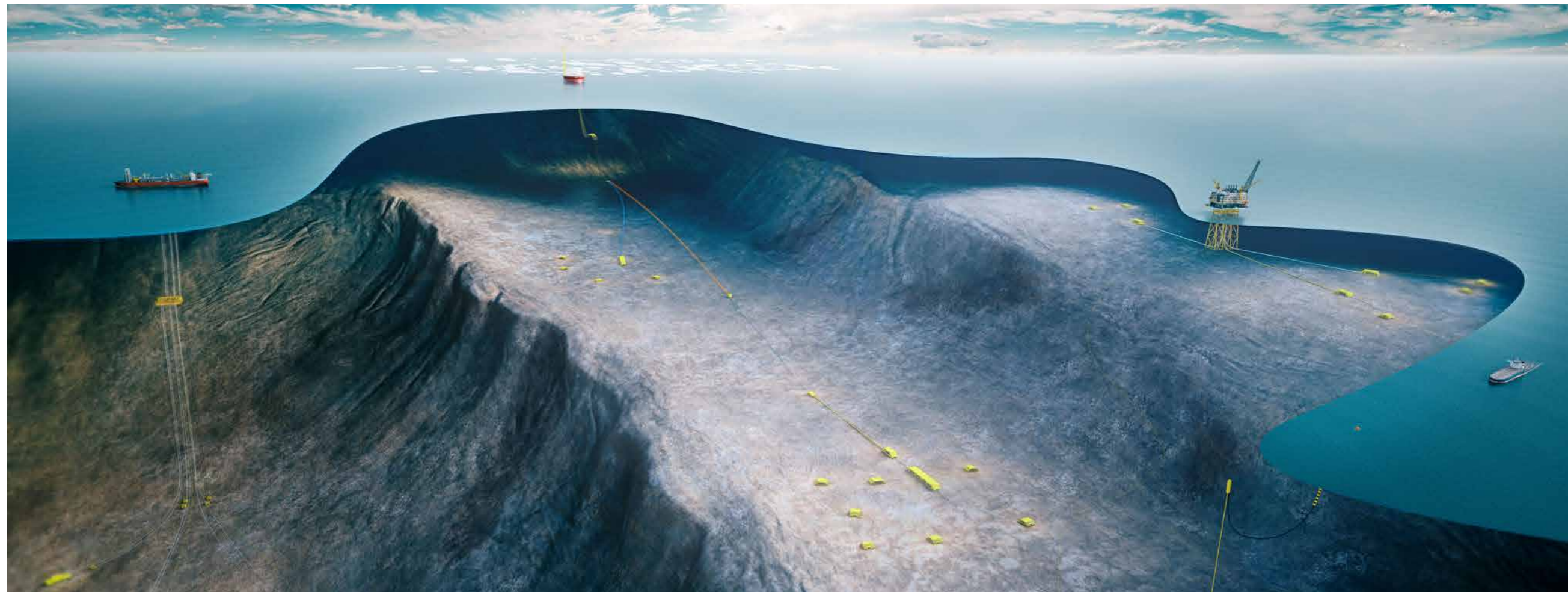
DEH and EHTF are effective complementary technologies, covering different ranges of U-values and Overall Heat Transfer Coefficients.

Pipeline Bundles

Pre-assembled Pipeline Bundles, in which we are acknowledged world leaders, are another extremely effective technology for extending subsea infrastructure lifespans and reducing field development costs.

Pipeline Bundles can incorporate hot water circulated close to the production pipe within the Bundle cross-section, as fully preassembled subsea systems containing multiple flowlines and service lines packaged inside a carrier pipe.

Multi-bore Bundle-to-Bundle connector systems are currently under development to improve the economics for longer tie-backs by using multiple Bundles.



We are currently assessing the efficiency of circulated hot water in longer Bundles in this way, with the longest installation to date being a 27 km Bundle for BP Andrew in 2012. Hot water Bundle systems have the added technical advantage of heating the Bundle-to-Bundle interconnecting spools.

Cold Flow Systems

As tie-back distances increase beyond the effective capability of active heating systems, the flow assurance strategy moves from "maintaining the temperature above hydrate formation temperature" to "transporting under ambient sea water temperature conditions".

Subsea 7's new WCU is based on already proven technologies. The WCU offers clients an cost-effective strategy for achieving a safe

cold flow condition in the development of remote subsea fields.

We are currently assessing the boundaries of applicability for Cold Flow Systems for various tie-back distances and host platform alternatives, but the concept enables longer tie-backs at significantly lower cost than with FPSO or platform-based processing solutions.

Cold Flow Systems have game-changing potential in remote regions where there is a lack of existing infrastructure or where manned processing facilities are not possible.

Future prospects

Tie-backs in recent years have successfully brought remote resources to existing topside installations, using non-conventional technologies such as subsea pump boosting. For long-distance tie-backs (i.e. greater than

50 km for oil fields and 100 km for gas fields) conventional flow assurance methods to control hydrate and wax prevention are no longer applicable, either because technology reaches a limit (thermal insulation thickness) or because the cost of ancillaries (for example chemical injection lines) prohibits resource development.

Using the technologies profiled in this article, field architecture is now possible that enables production via very long-tie-backs, typically over 50 km for oil-dominated flowlines.

This enhanced subsea capability will allow the future development of brown-field and remote green-field reservoirs which have previously been regarded as uneconomic prospects using traditional platform-based or vessel-based production facilities. •



Olivier Lodeho started his engineering career in the automotive and diesel engine industries before moving into oil and gas R&D. His early projects with Subsea 7 involved the design of pipe-laying equipment including friction clamps and PLET handling systems. He now leads the Technology Department in our Global Project Centre in Paris and the Strategic Flowline Technology Development Program.



Sigbjørn Daasvatn started his offshore career as a diver and field engineer before progressing to project engineering. He also has extensive experience from various positions in both onshore and offshore operations from an operator's perspective. He founded and managed a prefabricated construction company before returning to offshore engineering with Subsea 7, where he now leads the strategic development of subsea processing from our Stavanger office.

PIPELINE BUNDLES & TOWED PRODUCTION SYSTEMS

ENABLING THE NEXT GENERATION OF SUBSEA ARCHITECTURE

By **Sigbjørn Daasvatn** | Strategic Technology Programme Manager for Subsea Processing & **Martin Goodlad** | Strategic Technology Manager for Bundles R&D

Subsea 7 effectively pioneered the onshore prefabrication of subsea systems with our unique Pipeline Bundles, which offer a versatile and cost-reducing alternative to conventional pipelay-based subsea installations.

To meet the increasing challenges of field development, we continue to enhance the capabilities of this market-proven specialist technology. Our new-generation Bundles are higher-performing, smarter and suitable for an even wider range of applications.

Our Pipeline Bundles are now also complemented with the development of Towed Solutions, which are similarly based on efficient onshore prefabrication, modularised design and fast, low-cost towed offshore installation. The result is a world-leading portfolio of subsea solutions with major advantages over platform-based systems.



The Towed Solutions concept

The central principle of our Towed Solutions is our ability to efficiently incorporate individual subsea processing units from a wide range of equipment providers on a “plug and play” basis within an open integration modular platform.

This allows us to deliver fit-for-purpose functionality with a wide range of fully pre-qualified provider elements selected from our extensive subsea toolbox and installed on an integrated subsea structure.

This system, with its standardised interfaces, allows for the re-use of components and systems, enhancing the already significant CAPEX savings and opening up the possibility of new commercial models for marginal, short-life fields.

The integration and testing of the systems during their onshore assembly offer greater reliability than offshore testing, and, by its nature, the concept is designed to be flexible and scalable throughout the full lifecycle of a field.

As with our Pipeline Bundles, significant cost reductions are also achieved by using a fast, accurate towed installation technique which requires no specialist pipelay or heavy lift vessels.



Pipeline Bundles incorporate single or multiple flowlines, injection lines and control umbilicals within a rigid, large-diameter carrier pipe.

Pipeline Bundles: the advantages

For 37 years, Subsea 7 has been the recognised world leader in the design and onshore fabrication of Pipeline Bundles, of which over 80 have been installed to date in UK, Norwegian, Dutch and Australian waters.

Each of these Bundles was functionally different, to meet individual field conditions, which demonstrates the versatility of the concept. Depending on the nature and location of the field development, Pipeline Bundles have delivered cost reductions of between 12-20% when compared with conventional pipelay installations.

PIPELINE BUNDLE TECHNOLOGY DEVELOPMENT

MONITORING & DIGITALISATION

- Strain & temperature monitoring
- Reduce design conservatism, active operation of flowline system
- Hydrate monitoring
- Leak detection

CAPITAL EFFICIENCY

- Bundle Connector System
- Design for manufacturing
- Lower cost materials

ENHANCED PRODUCT

- Deep Water Application
- Heated Flowlines
- Global deployment

PRODUCT INTEGRATION

- Open integration platform
- Boosting & Bundle systems
- Well Slots

ENHANCED OPERATIONS

- Standard USB connection for Autonomous Vehicles

The principle of the Pipeline Bundle fabrication technology is simple: all structures, valves, pipelines and controls for field operations are fabricated, assembled and function-tested onshore in optimal controlled conditions.

The flowlines, together with control umbilicals and injection lines, are packaged within a large-diameter single carrier pipe which terminates with a towhead structure or manifold at both ends.

Pipeline Bundles have three significant benefits over conventional pipelay and subsea installation methods:

- Ability to incorporate a wide range of pipeline materials to meet the most challenging flow conditions
- Cost-effective and flexible towed installation with no need for specialist pipelay or heavy lift vessels
- An increased capability to incorporate wide-ranging subsea process functions within the system, either built-in during fabrication or linked post-installation via standardised connectors.

Our well-established Pipeline Bundle concept is being further developed to enhance its range and accommodate advanced ancillary control, power, communication and monitoring systems within its carrier configuration.

Trials are advancing on using temperature sensors and fibre-optic monitoring systems for strain, temperature and hydrate formation. These successful trials have significance for future HP/HT Pipeline Bundle applications and are moving towards full field qualification.

We are successfully extending both the depth and delivery ranges for Pipeline Bundles. Having demonstrated our capability to install Pipeline Bundles in depths of around 1100m using additional nitrogen in the carrier annulus, we are now proposing increasing that range to around 1500m with the application of a low-cost external buoyancy pipe.

To enable multiple Pipeline Bundle structures in excess of 33km, we are in the detailed design phase of a new multi-bore connector system which will greatly enhance the scalability of the product. Along with other planned fabrication developments, this extends the delivery range of Bundle transportation to a maximum of 2000km with no significant increase in structural fatigue during the tow.

In anticipation of the use of Autonomous Vehicles for long-term Life of Field maintenance, Pipeline Bundles are now pre-assembled with ready-fitted standard USB connections for data transmission and inductive power systems.

Flowline performance options

The large-diameter carrier pipes provide a corrosion-free environment, which can in itself reduce the need for individual corrosion coating of flowlines.

To meet demanding flow assurance and/or corrosion resistance specifications, however, the rigid design of the Bundle allows us to select from our market-leading portfolio of flowline performance options:

- single or multiple flowlines and umbilicals
- reduced wall thickness in internal flowlines
- active electrical heating systems, including hot water and EHTF
- circulated hot water heating systems
- high-performance insulation using low-cost materials
- heat transfer between adjacent pipes
- corrosion-resistant alloys or cost-effective mechanically lined BuBi® pipe
- polymer-lined pipe
- High Temperature and High Pressure service to 220degC, 1400bar

Installation benefits

Since Pipeline Bundles are fabricated onshore in a single, self-contained length, there is no requirement for offshore strength testing. The structure also provides a low-stress environment for the flowlines, with the carrier pipe withstanding fatigue loadings, while the on-bottom weight resists global lateral buckling and generally requires no trenching or rock stabilisation.

Subsea 7 has repeatedly demonstrated the cost-effectiveness, versatility and reliability of the Controlled Depth Tow Method (CTDM) for the installation of subsea Bundles and structures. This technique has been successfully used on Pipeline Bundles weighing over 10,000 tonnes, using only two conventional anchor-handling tugs.

Since no specialist installation vessels are required, fast, accurate offshore installation is enabled with significantly reduced marine operations.

The controlled depth tow can be performed in higher sea states than offshore lifting and significantly minimises field access requirements.

Existing carrier technology allows for Bundle installation in water depths to 700 metres, and potential installation depths to around 1500 metres are possible by using low-cost external buoyancy pipes.

Pipeline Bundles installed to date have not exceeded 7.6km in length, this restriction reflects the current capacity of our specialist fabrication yard in Scotland. Analysis has confirmed that considerably longer Pipeline Bundles can be towed by CTDM.

Recent studies also confirm that fatigue induced in Pipeline Bundles on longer transit journeys to more remote locations can be addressed and mitigated. As we demonstrated with a 27.1km Pipeline Bundle tie-back for BP's Andrew Field in 2011, the concept

is also scalable. The Andrew installation consisted of four interconnected Bundle systems, and we have since developed multi-bore Bundle Connector Systems that will enable multiple Bundle structures in excess of 33km.

We have successfully introduced product modularisation into Pipeline Bundle assembly with our recent integration of boost pumps within the towhead. We have designed a module component to house a 70-tonne multiphase boost pump which is efficiently installed using a standard module handling frame. This system allows for economic future installation (delivering cost savings around 80% over a conventional retrofit assembly) and makes pump module enhancements possible.

Lifted or towed installation?

Conventional construction vessels have crane capacities of around 400-600 tonnes, and, although flagship vessels like the

Seven Arctic can lift up to 900 tonnes, deployment operations of this type can still restrict the workable weather window.

Through our delivery of prefabricated Pipeline Bundles since 1980, Subsea 7 has developed world-leading capabilities in the design, engineering, procurement, onshore construction, launch, tow-out and installation of these prefabricated systems. Pipeline Bundles have included more sophisticated manifolds and SSIVs, cooling/warming spools, HIPPSs and boosting pumps and other integrated functionality.

The next stage is to extend the scope of this cost-effective and reliable technology by building up prefabricated towed structures into complete subsea production facilities, or, for larger fields, by combining a number of systems, such as subsea processing and wax control within a single structure. Our world-leading expertise in the design of modular subsea structures is based on our wider field development capabilities, which enable us to select from alternative flow concepts to optimise field architectures and economics.



Onshore assembly and testing of the plant.

The Modular Integrated Platform

Our most recent development is the Submerged Production Unit (SPU), a versatile hybrid structure designed to house large subsea processing plants which are assembled onshore in specialist yards.

The SPU comprises three main structural elements – a steel deck to support the processing modules, a GRP superstructure to carry the heavy pay loads during towing and installation, and required buoyancy for the tow. The SPU is a ground-breaking concept which can be fully prefabricated onshore and system-tested before tow-out.

To optimise our portfolio of technical possibilities, the SPU is a modularised system that enables the rapid integration of pre-qualified equipment units from a number of providers into the product via standardised interfaces.

As a fully integrated structure, the SPU is designed to maintain its production profile

throughout the operating field life with minimal downtime. Modularised design enables the efficient retrieval of processing modules with serviced maintenance requirements.

The modular integrated platform allows for the re-use of components and overall system to create significant CAPEX savings and new commercial models.

With many marginal fields having an estimated production life as short as three years, the modular integrated platform can provide a step change in the way these fields are developed. This enables the development of new contracting strategies and the distribution of cost across several successive field developments, making uneconomic small pool development viable.

The main benefits of modularisation are realised through our Subsea Technology Toolbox, a digital design library of established and emerging technology models which are qualified for open integration into new field solutions.

Through wide industry collaboration, these extensive ranges of 3D models are modularised with standardised interfaces to allow efficient integration into field-specific system configurations.

This library of parametric models and sections greatly accelerates the design process while still allowing our engineers to tune and optimise product templates to meet local field requirements and architecture. This in turn reduces the assembly time for large subsea structures with provider equipment being integrated into the product platforms as efficiently as possible.

Critical assembly steps can be “de-bottlenecked” in this way, and standardised, qualified components can be deployed in successive projects without significant re-engineering.

Modular component repeatability also reduces procurement complexity and delivers assembly productivity gains through shorter, higher-quality lead times.



Subsea Toolbox.

Transport and installation frame

Subsea processing systems can consist of a variety of individual processing units from different equipment providers. The central principle of the Towed Solutions is the application of standardised and modularised designs throughout the system, allowing the incorporation of a wide range of systems as for a topside platform module.

Subsea 7 has developed a standardised Transport and Installation Frame (TIF) which allows individual modules to be installed into the SPU on a “plug and play” basis. In an ideal scenario, TIF uses vessel moonpool installation to minimise weather dependency, although over-the-side lowering is also possible.

This effective transport system is based on Subsea 7’s extensive experience of subsea operations and allows for the integration of market-proven processing equipment into a fully-functioning, pre-assembled subsea system.

Total subsea solutions

Scalable global subsea systems are therefore a market-ready proposition. New-generation Pipeline Bundles and Towed Solutions are highly compatible with the anticipated adoption of Subsea Production, Storage and Offloading (SPSO) facilities.

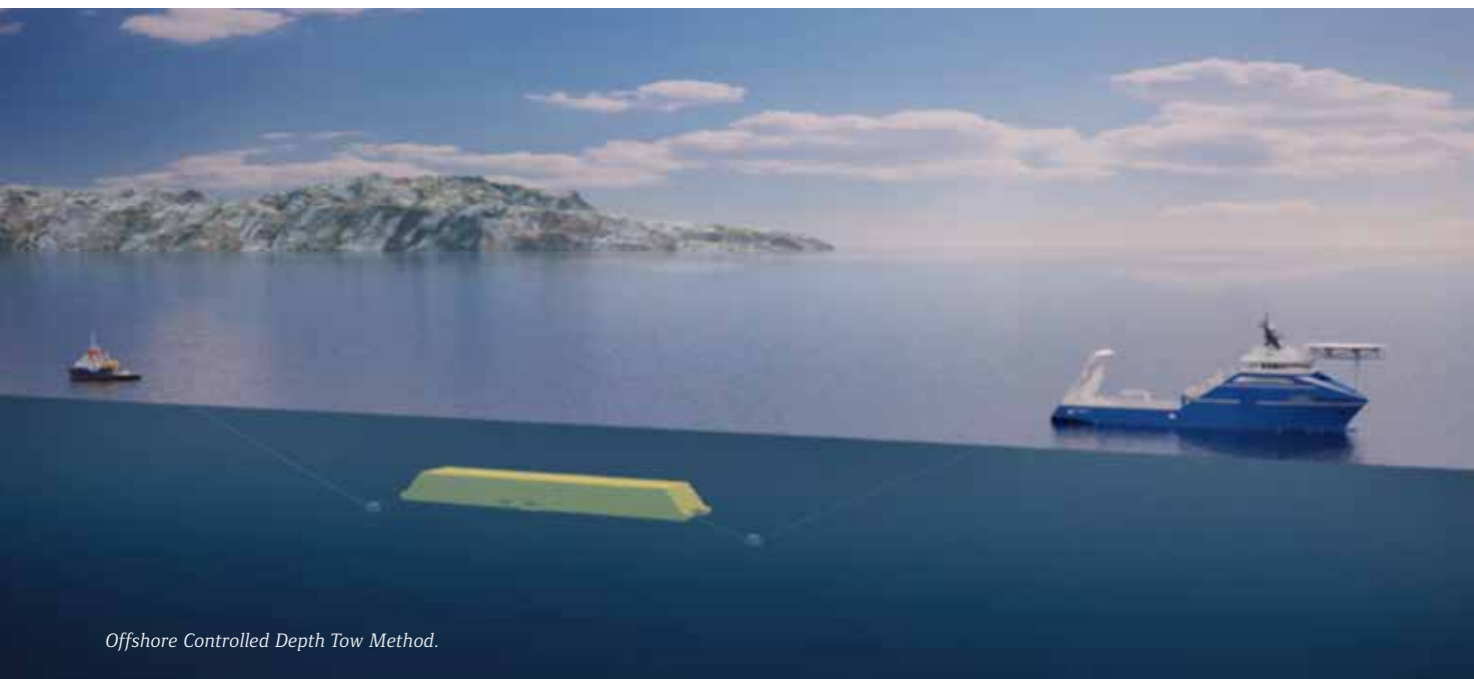
Based on market-proven technologies and demonstrating great versatility in both functionality and scope, Subsea 7’s prefabricated subsea systems can be designed, fabricated and installed at cost levels significantly less than with conventional pipelay and heavy lift

” *Game-changing technology platform which will enable the next generation of subsea architectures; significantly reducing costs and providing re-usable, scalable solutions to our clients*

installations. Based on a common reliable and cost-effective installation method, the products will enable the economic development of tie-backs, challenging small-pool and marginal reserves for many years to come. •



Martin Goodlad manages Subsea 7’s Pipeline Bundle Technology Development activities. He joined us in 2002 as a specialist Pipeline Bundle design engineer and also worked on our new-build vessel programme. Martin previously worked as a Naval Architect in classification societies, shipyards and the defence industry, where he was first introduced to offshore oil and gas through converting pipelay boats, drill ships and seismic survey vessels.



Offshore Controlled Depth Tow Method.

Developing the future of IRM through innovation

By Adrian Dayani | Global Technology, i-Tech Services



Operating companies are increasingly focused on their operational expenditure on complex offshore infrastructures. i-Tech Services is challenging itself to look for innovative integrity management technologies, that will optimise maintenance activities and lower the Total Cost of Ownership.

Clients want to maximise their return on investment, keep their ageing assets in operation for longer and concentrate more on the Total Cost of Ownership in investment decisions. To achieve this, i-Tech Services is focused on delivering an aggressive technology development plan that, at its core, utilises big data, digitalisation and Artificial Intelligence to provide an Intelligent Asset Management Service.

By utilising design data, as-builts, actual inspection and survey results, metocean and operating data, packaged in a 21st century viewer, the goal is to provide predictive asset management that can provide real-time equipment health and condition ratings. These include

recommendations on when to perform maintenance based on client goals, needs and other constraints (including weather, logistics and geo-politics).

A big data platform in isolation is not the answer. We have repeatedly heard from clients that they want to reduce the cost of operating expense (OPEX) as well as minimise vessel and people utilisation offshore; we must become more efficient and innovative. On greenfield developments, designing for monitoring, maintenance, intervention and system reliability is a critical element in enabling i-Tech Services to align with Subsea 7's technological and operational expertise. For brownfield, however, being more responsive, lowering the cost of inspections, collecting the right data to determine equipment health and having the capabilities to intervene, repair, extend and dispose of assets is equally important. So, while greenfield offers opportunities to install new technologies and ways of working, we are continuously investigating how these can also be retrospectively applied to brownfield sites.

The amalgamation of our former Life of Field (LOF) into i-Tech Services has given us a more comprehensive tool kit, strengthened our capability and

assembled a dedicated group able to focus on our clients' needs. It has focused the technology programme on becoming more efficient, expanding our overall capabilities to be able to lower the Total Cost of Ownership of new and existing fields.

The technology development programme is focused on the following areas;

- Hosted and Autonomous systems, to reduce costs by moving people from offshore to onshore centres, whilst providing a better response to collect data and intervene as needed.
- Condition Monitoring Sensors to allow the right information to be collected.
- Data systems, process automation and intuitive client information access to process the data quicker and more reliably.
- Intervention and Repair Tooling, including pipeline repairs and hydrate identification.
- Tools and techniques that will allow us to mobilise more quickly, manufacture more cheaply and fast-track developments.

Our objective is to build on our extensive in-house technological design and

development capabilities to become the leading global Life of Field service provider. To achieve this goal, we are collaborating with some of the biggest, most innovative companies and well-known brands in the world, developing a peer network with other industries, academia and using open innovation platforms to identify trends or solutions used in other industries that would be transferable and applicable.

What developments can you expect to see from us in the near future?

Pipeline and riser repairs

Following on from the success of our Emergency Pipeline Repair System (EPRS) Project offshore Australia, the development of faster deployable pipeline repair solutions including ROV deployable epoxy wraps and an epoxy-based repair clamp to allow deepwater repairs with scalable delivery and a fast, flexible response.

Autonomous, remote and hosted technology

The development and testing of the original AIV gave us a solid platform for development of the sophisticated autonomous vehicle. We have successfully deployed autonomous surface vehicles to perform metrology and other survey-related tasks. Sophisticated autonomous vehicles based on our existing AIV will deliver a significant value proposition to our clients. This is only the beginning of an exciting phase where we are developing remote piloting systems, beyond restricted 4G network capabilities, and pilot assistance solutions. These include machine intelligence and autonomous capabilities to perform tasks that can greatly assist operations, reducing user fatigue or human error and similar in concept to aviation autopilots or airport visual recognition systems.

Advanced identification sensors

We are currently evaluating and working with technology providers in developing new solutions to enable early hydrate, corrosion and cathodic protection and identification through non-intrusive and non-contact methods.



The Emergency Pipeline Repair System.

Rapid fly-by external inspection using a non-contact sensor for ROV, AUV or AIV deployment to identify wall thickness, hydrate and wax anomalies or the status of CP systems is critical in enabling time-efficient inspections and determining the health of structural assets.

Evolving technologies allow us to deploy chemical injection solutions or localised remediation solutions earlier and more effectively.

Integrated data management

Using automated anomaly identification and data processing systems, our data management program, will be able to process and prioritise data to provide high-

quality, timely reporting in line with all the client's requirements and systems.

We have developed a unique data architecture with Application Programming Interfaces (APIs) that allow us to maximise automation, integrate all types of sensors and software platforms and introduce unique i-Tech services apps to optimise the acquisition, management and, most critically, access to intuitive smart data.

The benefits include enhanced quality control, faster report delivery, improved data security and reduced resource requirements. Fundamentally, it will allow our clients to concentrate on their critical, high-value datasets to deliver insight and information. •



Adrian Dayani has over 20 years' technical management and product development experience in developing intervention and asset management solutions for the power generation, electric utility, defence and oil and gas industries. Based in Houston, he is responsible for market opportunity analysis and technology evaluation/implementation for i-Tech Services.

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